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PRECIPITATION MAPPING

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13. ABSTRACT (Maximum 200 words)

Techniques have been explored for the automated detection and characterization of precipitation areas in weather radar data. The purpose of this effort is to develop guidance for the operational forecaster for the NOWCASTing of start and stop of precipitation. Precipitation intensity is not considered in this effort. Two techniques have been adopted to extract precipitation areas from the radar reflectivity fields: contour extraction and edge detection. The first method allows the selection of regions within a storm that the forecaster considers to be significant. An efficient technique for the extraction and characterization of the contours based on the Freeman Chain Code has been adopted. The other technique is an edge detection technique that is based on gradient of reflectivity factors. This has the capability of detecting more of the internal structure of the storm and to characterize the regions along the outer edge where the weather might be more intense. This latter technique produces lines like the contour method that can be characterized by the Freeman Chain Code. Efficient techniques for the characterization of these lines or areas encompassed by these lines have been developed based on the chain code. It has been found that a combination of the contour and edge (contd)

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:m #13 Abstract continued

:ection is a powerful tool that permits interpretation of the location and subsequent
'ement of precipitation areas and also an indication of changes in intensity.

FOREWORD

This Scientific Report details the results of research performed by ST Systems Corporation (STX) under Contract F19628-87-C-0124 with the Atmospheric Sciences Division, Geophysics Laboratory.

PRECIPITATION MAPPING

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I. INTRODUCTION

Accurate short-term forecasts of precipitation are required for a variety of both public and military purposes. With regard to military operation, such forecasts are needed for general air terminal operations and for satellite communications. Weather radar provides one of the best methods of detecting and mapping precipitation with the temporal and spatial resolutions required for short-range forecasts. Spatial resolutions of 1 to 4 km are possible within 230 km of the radar, with data collection every 5 min. This resolution is sufficient to monitor the motion and evolution of most precipitation systems, including convection storms. While the data are sufficient, automated monitoring techniques are required to realize the full potential of radar for nowcasting purposes.

For precipitation forecasting, there are two (at least) approaches that can be taken: the forecasting of precipitation amounts and/or the precipitation location. The estimate of precipitation amounts is a large problem unto itself, let alone attempting to forecast changes. A more realistic goal is to forecast locations, either for an entire precipitation envelope or for arbitrary intensities as indicated by reflectivity factors. This report describes techniques that have been adopted to extract characteristics of radar observations that will lend themselves to the forecasting of precipitation locations for time periods of 0.5 to 1 hr. It should be reiterated that the goal of this effort is to develop the location and <u>not</u> amounts of precipitation.

II. CHARACTERIZATION TECHNIQUES

The basic approaches to be presented rely on the extraction of contours to characterize the perimeter of the detected precipitation area. These are the lines that can be used to forecast the onset and stop of precipitation without monitoring every pixel or range gate of data. This drastically reduces the amount of data to be forecast while still fulfilling the intent of the task. There are several ways of defining contours that describe the edge of data:

- Selection of a threshold reflectivity factor value and interpolation among gridpoints to define a precise contour of constant reflectivity factor.

- Selection of a threshold reflectivity factor value and then definition of a line through the data points such that all values on and to one side of the line are equal to or greater than the selected value and all values on the other side of the line are less than the value. This again defines a line of constant reflectivity factor.

- Detection of the outer edge of an area through gradient techniques.

The first of these techniques provides a very precise way of extracting contours but is very costly in terms of computer time. The second technique will produce a similar but slightly less precise result. However, it takes much less computation time, particularly when use is made of efficient ways of extracting, and saving and manipulating these latter contours.

The gradient techniques are based on the observation that the edges of radar echoes are usually characterized with large gradients of the logarithmic reflectivity fields (expressed in dBZ). In the field of imaging processing, efficient techniques have been developed for the computation of gradients of fields and for the construction of lines of maximum gradients that are interpretable as edges. These appear to be readily applicable to radar data.

These latter two techniques will be discussed in greater detail. Analyses will be presented to show the utility of each technique and the complementary nature of the results.

A. Contour Extraction

Contours of reflectivity have the benefit of providing an indication of the area within which the precipitation is equal to or greater than a prescribed amount. From previous studies (Bohne and Harris, 1985 and Bohne et al., 1988) it has been concluded that a technique developed by Freeman (1961) that used the Freeman Chain Code (FCC) (or a variation of it) is highly effective. This technique works best when the data have been interpolated onto a rectangular Cartesian grid. Basically, it searches for a start point where a data value is equal to or exceeds the desired reflectivity threshold and the coordinate for that point is recorded. Then an eight-direction search is conducted about that point to find the next location for the contour. A directional value as given in Fig. 1 is assigned to that grid point. Only that directional value is retained for that point. This search is then conducted about the new point for the next value until the search reaches a data edge (i.e., the maximum range) or returns to the start point. In this way a contour is completely defined with a start coordinate and a series of directional codes. This represents a simple, fast, and efficient contour extraction routine.

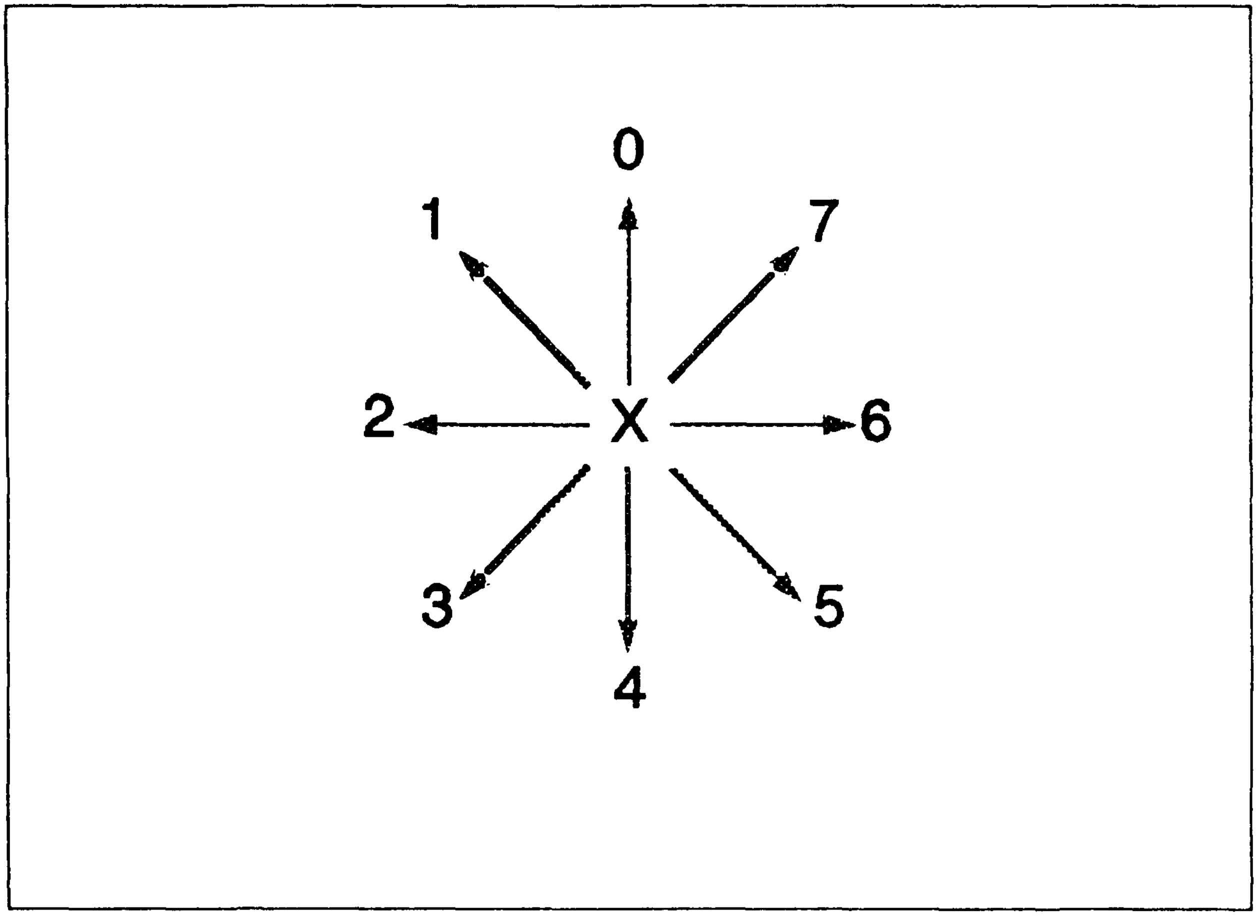


Figure 1 Freeman Chain Direction Codes.

B. Edge Detection

The main limitation of the above techniques is the same as for all contour definition methods: It defines a specific reflectivity contour but does not detect the true edge of the precipitation. In some cases, it is important to know where precipitation of any magnitude is located. This is especially true for those operations that use high-frequency transmissions.

Hamann (1990) has developed a technique that uses image analysis to detect edges of precipitation regions. The Hamann technique is based on the computation of gradients using an efficient template approach. Two fields are computed: a magnitude and a direction value for each valid data point. It then uses both fields to construct lines of maximum gradient. Gradients of reflectivity tend to be maximized along the edges of echoes when the data are presented in DBZ format. This technique does not depend upon reflectivity reaching and maintaining a specified value for a contour to be defined. The resultant edge contour may, in fact, cross reflectivity factor contours.

C. Feature Characterization

To this point we have detailed two techniques to contract lines around precipitation echoes. The contour extraction technique automatically provides a simple representation of a line. The line resulting from the edge detection scheme can also be represented in that form. This means further analysis techniques can be based on the FCC and will be valid despite the source of this line. From the Freeman Chain Code if the contour is closed, the area, contour, and orientation of the major and minor axes can easily be computed. These are all useful parameters for forecasting purposes. The dominant or most frequently occurring FCC value indicates the major axis orientation. In addition, monitoring the magnitude of the gradients may indicate changes in the precipitation structure. This latter aspect is beyond the scope of this study.

III. TECHNIQUE IMPLEMENTATION

A. Preprocessing

Preprocessing consists of transformation of the data from spherical to rectangular Cartesian coordinate systems, editing to remove spurious data, and filtering to decrease the spatial variability of the data. The first of these tasks is simply a rasterization of the data to allow the easy implementation of image processing techniques. Two methods were readily available for this purpose: one is more predictable in terms of the scale of filtering involved while the other is computationally much more efficient. The more predictable method is a bilinear technique developed by Mohr and Vaughan (1979) while the faster technique is one implemented by Cohan (1990) for real-time operations.

The Mohr and Vaughan (1979) technique is a three-dimensional interpolation technique that takes the eight nearest data points (four above and four below) to a Cartesian grid point using one of several weighting functions. Their implementation involves the presorting of the Cartesian grid data to be consistent with the organization of the radar data as it is received.

Cohan (1990) implemented a computationally fast technique that requires minimal computations. It basically stores the radar data as it is received into the nearest Cartesian bin, where the last value into a bin is the one retained.

Of these two techniques, the Mohr and Vaughan (1979) technique will better preserve the fluctuations that were in the original data. There is some filtering of the data but the degree of filtering for various scales can be predicted. However, for the processing of data in realtime or for the processing of large amounts of data, the Cohan (1990) implementation is much more efficient.

Since only small amounts of data have been processed to date, and data accuracy is still considered important for the types of computations (particularly gradients) to be performed, the Mohr and Vaughan (1979) interpolation scheme has been used. It is anticipated that once more extensive testing is required, the Cohan scheme will be the more useful.

Once the data are in a Cartesian format they can be filtered to remove noise and small scale features that would complicate either the contour extraction or gradient detection routines. A low-pass filter was selected to remove such features. Weights are applied to the data to compute a mean value for the central data point according to the formula

$$\overline{D_i} = \frac{\sum_{j=-N}^{N} [W_{i+j} \, D_{i+j}]}{\sum_{j=-N}^{N} W_{i+j}}$$

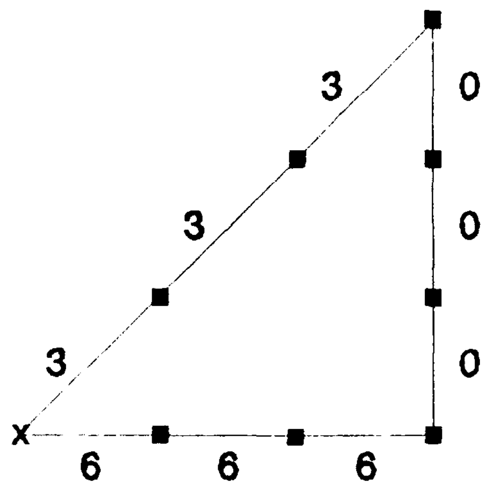
where D_i is the data value at the central grid point and W_{i+j} is the weight applied to the (i + j)th data point. Even with this filtering not all extraneous features are removed and further editing of the contour and gradients is necessary. However, at this point this level of processii g has been conducted somewhat manually on a case-by-case basis.

B. Deriving Feature Characteristics

Contours and edges (lines of maximum gradients) are computed for each precipitation region and various characteristics of the regions are derived from the Freeman Chain Code description of the lines. As noted before, this approach reduces the data field over which the calculations are made and thus reduces the amount of time needed for calculations.

The area of the precipitation feature (as defined by a contour or edge) is computed directly from the Freeman chain code values. As the boundary moves up or down adds or subtracts to the total area by an addition of a summed y-axis value. Each boundary move left or right decreases or increases the summed y-axis value. Slantwise moves involve a combination of both the area and the y-axis values changing. Every value in the Freeman chain code array contributes to the computation of the area. Fig. 2 shows an example of the resulting area within a simple triangle.

From the chain code representation, the perimeter and area centroids can be computed by



FCC = { 6, 6, 6, 0, 0, 0, 3, 3, 3}

Area = 4.5 Perimeter = 10.24

Figure 2 Freeman Chain Code Representations for a Simple Triangle along with Resulting Characteristics

$$Perimeter = \sum \max(\Delta X, \Delta Y, \sqrt{(\Delta X)^2 + (\Delta Y)^2})$$
$$Area = \sum \overline{X}\ \Delta\ Y$$

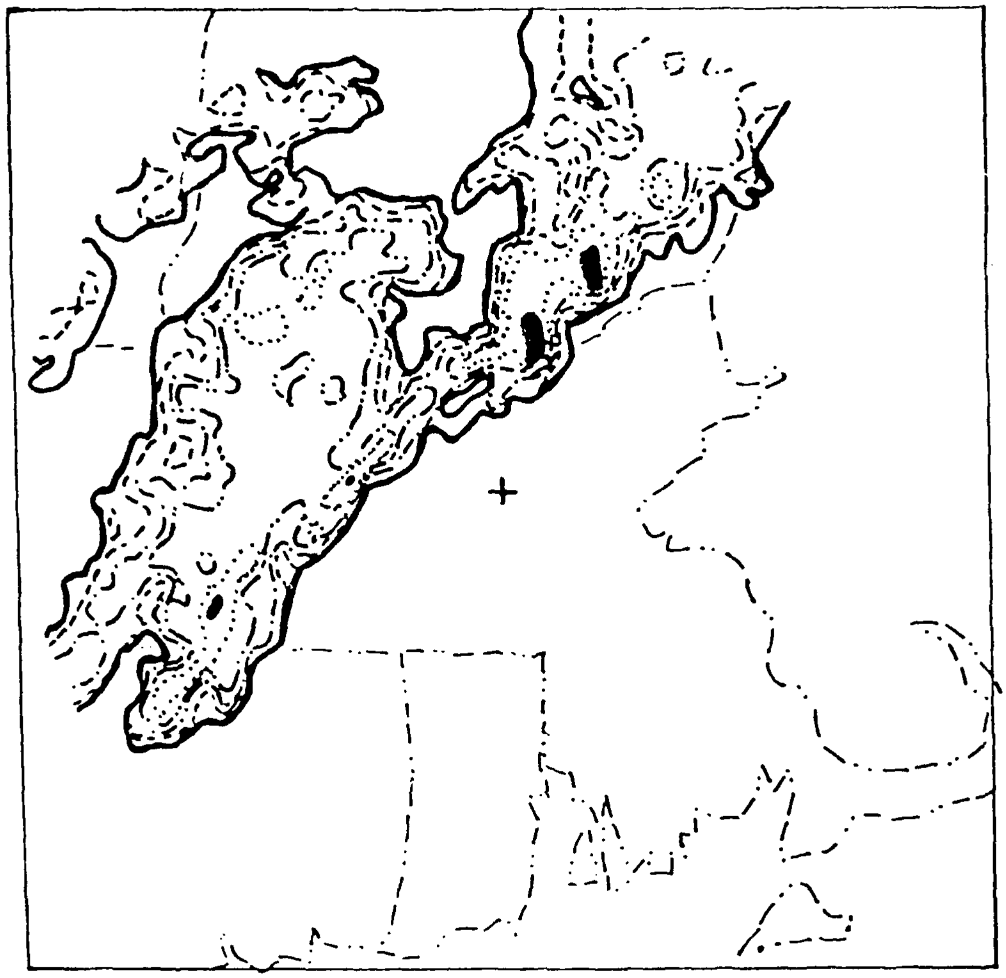
where $\overline{X}$ is simply the mean X between grid points. While the perimeter expression appears to contain many computations, it is merely a series of additions. If X does not change, then the Y term is added; if Y does not change the X term is added; or if both change then the third term is added. In addition, the frequency of occurrence of directional codes can be monitored, with the most frequently occurring value indicating the orientation of the contour, whether a vertical (north south), horizontal (east-west) or slanted orientation.

An approximate center of area is given by the mean X and mean Y point. The approximation provides a unique center of area for each precipitation feature, though the resultant mean (X, Y) point can be located outside the precipitation region with highly concave contours.

C. Analysis Presentation

Figs. 3 through 6 depict reflectivity analyses for data collected by the Sudbury radar at 1734 GMT, 26 May 1984, as a cold front passed over New England. Reflectivity factor contours at 7.8 dBZ intervals starting at 0 dBZ as derived from the color representation of this field are presented in Fig. 3. These contours are entirely consistent with those that would have been derived from the simplified contour extraction routine described above. The difference is that the contours in this figure have been visually estimated and there is no numerical description to locate accurately each contour. To perform objective calculations on the contour, it is still necessary to extract objectively the locations of each point along each contour.

Fig. 4 presents the area enclosed within the 23.5 dBZ contour from the Geophysics Laboratory radar processor. Comparison of this area and the contours in Fig. 3 reveals that the enclosed area contains the more significant precipitation regions but does not provide an envelope around all precipitation seen by the radar. Fig. 5 depicts the edges as determined from the gradient fields. Note that there has been no attempt at this point to eliminate insignificant features due to size in this analysis nor has there been any attempt to join the segments into a coherent, well-defined edge. That portion of the software requires refinement before useful products will be obtained. However, when the fields of Figs. 4 and 5 are overlaid, Fig. 6, strong agreement between the two fields is apparent. But this display also shows the complementary nature of these two analyses. The fixed contour presentation depicts the precipitation region in a simple form, indicating quite well where precipitation is located. Monitoring the feature in this form can give a very good indication of the overall movement of the precipitation area. The edge analysis (Fig 5) appears to outline the leading edge of the precipitation extremely well, but is more intermittent in nature along the back edge This is of course due to the differences in the intensities of the gradients on each of these edges. In addition, gradient edges give an indication of where the more active regions within the precipitation area are located. For example, on the leading edge of the precipitation area extending from west-northwest to west-southwest two parallel edges can be seen. This is near the more cellular-like structure seen in Fig. 3. This would indicate a region worthy of special consideration. In addition, along the leading edge but in the sector from north to north-northeast (Fig. 6), the structure in the gradient field is more complex. This occurs near other cell-like structures. Another indicator, though not represented in these figures, is the magnitude of the gradient field. Gradient magnitudes tend to be greater near the more active precipitation



250 km

Fig. 3 Reflectivity factor field at 1734 GMT, 26 May 1984 as measured by the GL S-Band radar at Sudbury MA at an elevation angle of 1.4°. Contours are for 0 dBZ (solid line), 7.8 dBZ (dash), 15.6 dBZ (dash-dot), 23.5 dBZ (dash-dot-dot), 31.3 dBZ (dot), and 39.1 (shaded areas). State outlines are in a dash-dash-dot-dot pattern. The radar is at the "+" mark.

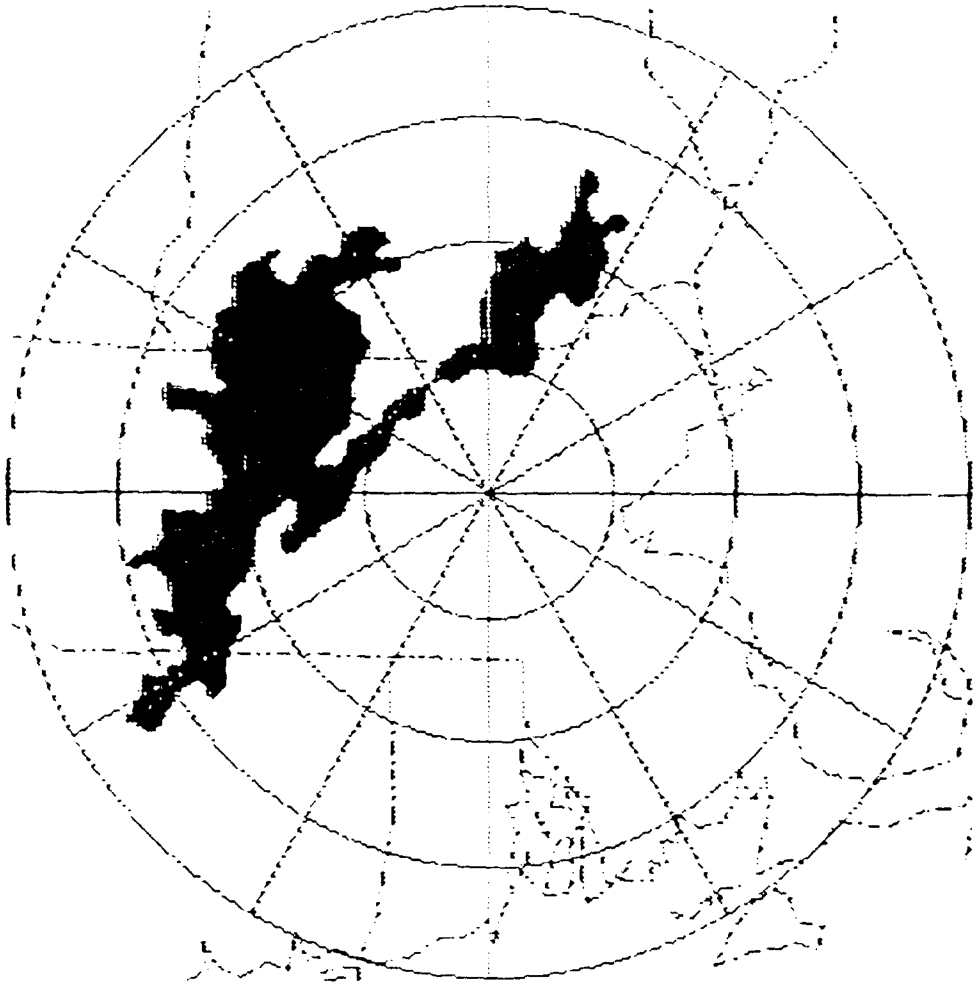


Fig. 4 Area in Fig. 3 where dBZ greater than 23.5 dBZ as depicted by shaded area. Contour used to outline this area was extracted and stored using the Freeman Chain Code approach. Range marks are every 30 km.

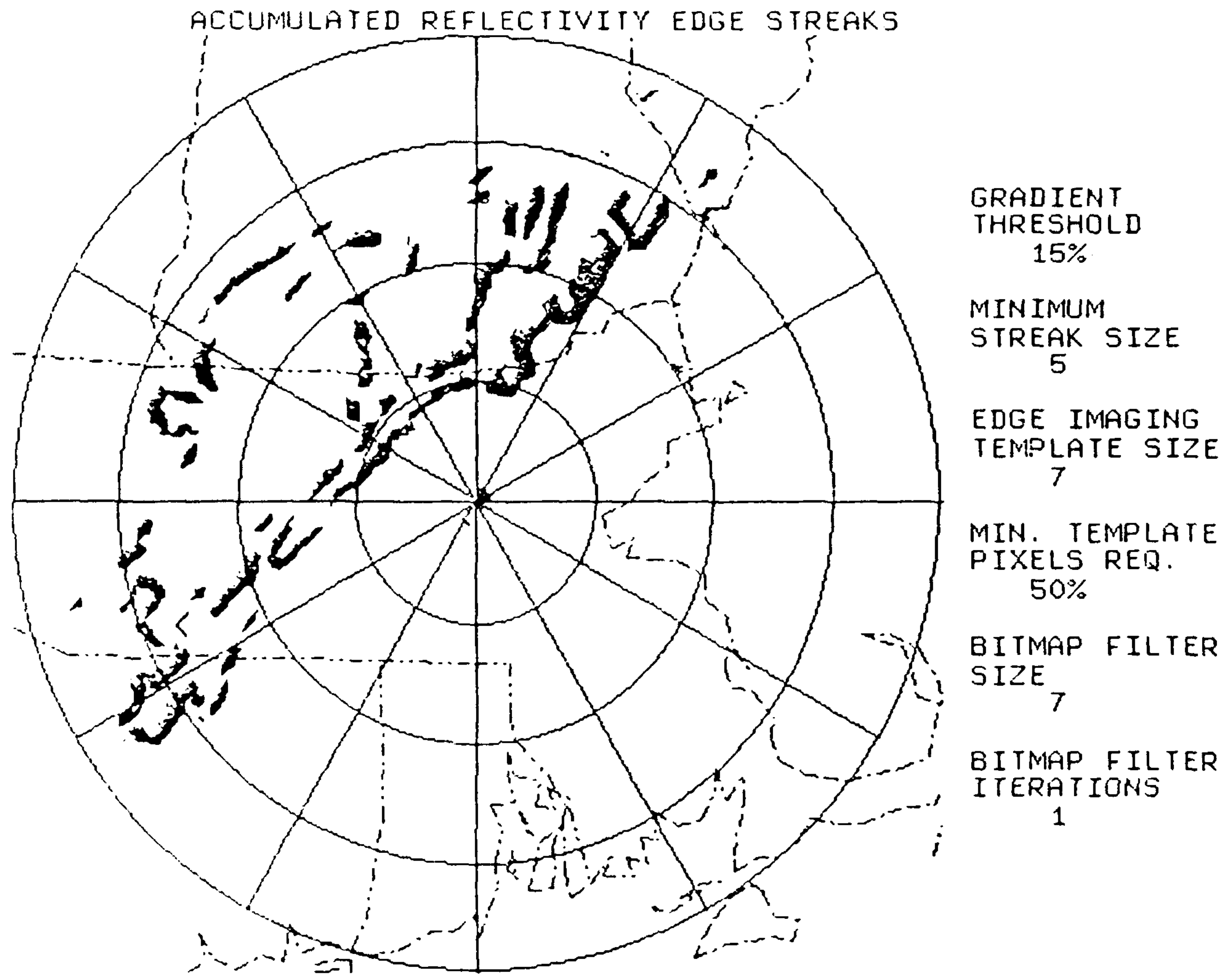


Fig. 5 Edges determined from gradient fields of reflectivity factors displayed in Fig. 3.

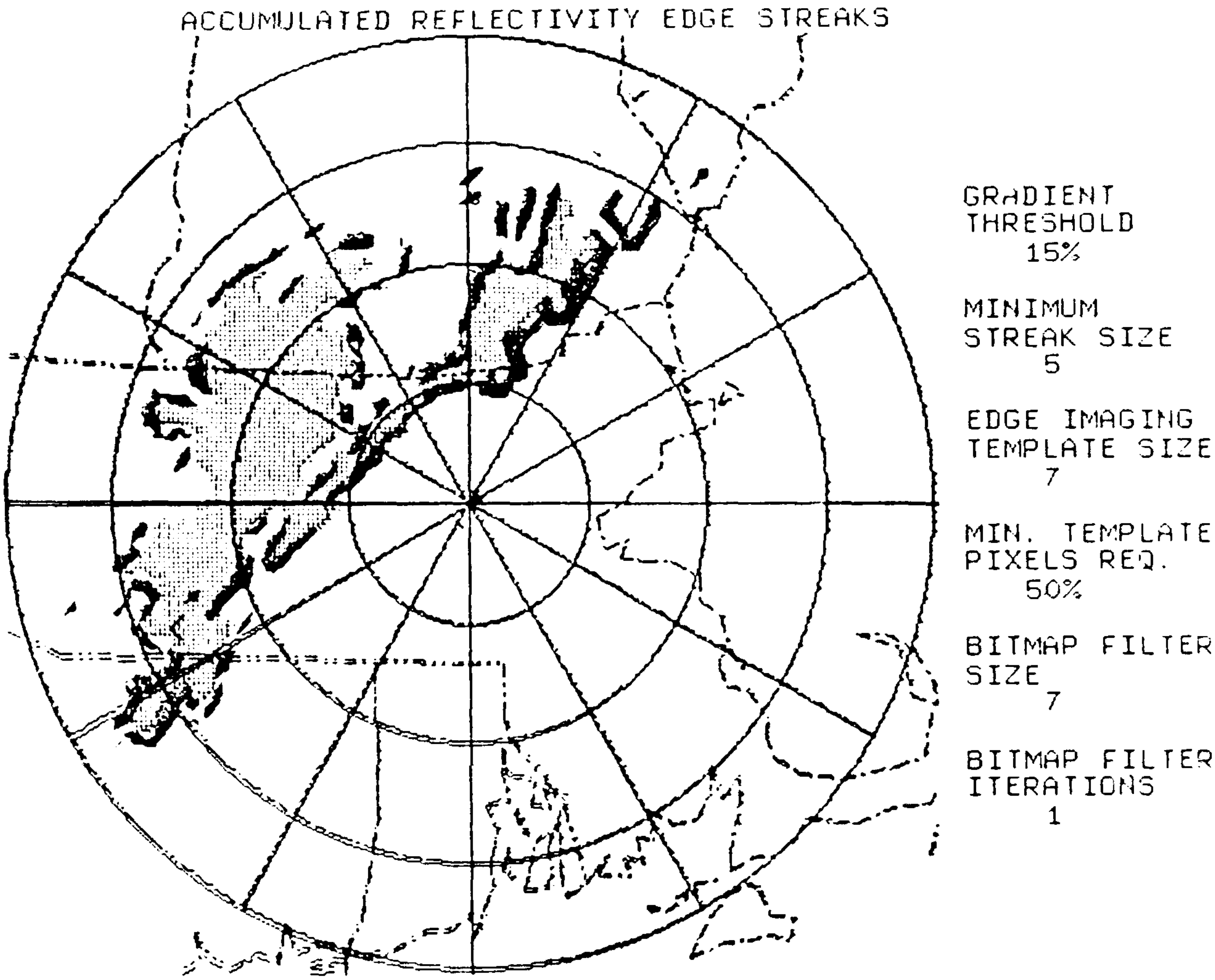


Fig. 6 An overlay of analyses of Figs. 4 and 5.

cells. The use of this parameter in terms of indicating precipitation structure requires further investigation.

On November 16, 1989, a narrow north-south line of precipitation accompanying a cold front moved through New England (Fig. 7). Here, the contours are at 6.6 dBZ intervals starting at 0 dBZ. The most intense precipitation is oriented north-south approximately 25 km west of the radar site. Behind this line the precipitation decreases very rapidly while extending to the east approximately 50 km. The area within the 20 dBZ contour is depicted in Fig. 8. This contour depicts the frontal region very well but is probably a little high to depict the overall region well. Note though, the contoured value is lower than that used for the previous case. This points out one of the deficiencies of using the contour alone to delineate precipitation regions. It is very difficult to select a universal reflectivity value that will depict all precipitation well. In Fig. 9, are the edges as determined from the gradient fields. Here, we see very distinctly both the leading and trailing edges of the line. Further, an examination of figures reveals a detected region in the immediate vicinity of the radar that most certainly is dominated by ground clutter. On the other hand, there is a region about 25 km to the south in both analyses that could be meteorologically real. The character of the contoured field (Fig. 8) for both features does not suggest any difference in the nature of the source of the echo. However, the gradient field (Fig. 9) is much more structured for the region to the south, consistent with that region being real and the area near the radar being due to clutter. This suggests that the gradient fields may be useful in distinguishing real from clutter data. In addition, the contour fields (Fig. 8) would appear to produce products that are much more trackable and therefore predictable than features derivable from the gradient fields (Fig. 9). However, techniques can be developed to construct trackable features from the gradient fields. If viable, use of the gradient fields should provide a means of excluding clutter features. This approach requires further examination.

IV. SUMMARY AND PROJECTION OF FUTURE WORK

In this report, we have presented two techniques for the delineation of precipitation regimes. The traditional contour method is presented but with newer extraction and representation modes. These modes are based on the Freeman Chain Code developed for image analyses. The value of this approach is the efficient extraction of contours and a representation that allows the simple computation of characteristics valuable for the monitoring of areas. Descriptive parameters of the regions are easily computed and can be used in tracking and predicting the movement of precipitation regions. While, the strength of contour representation of areas, particularly Freeman Chain Code representations, is in its implicitly, it is noted that the difficulty of

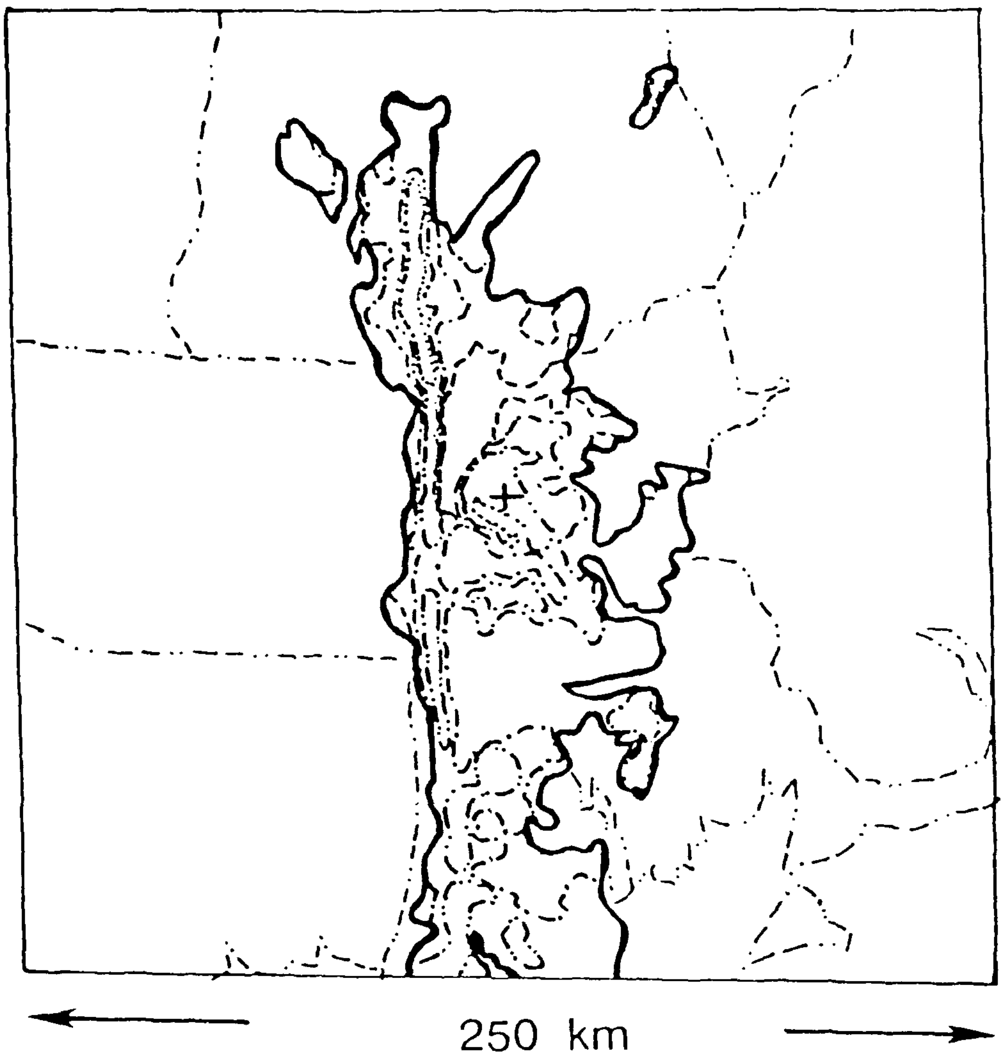


Fig. 7 Reflectivity factor field at 1624 GMT, 16 November 1989 as measured by the GL S-Band radar at Sudbury MA at an elevation of 1.4°. Contours are for 0 dBZ (solid line), 6.6 dBZ (dash), 13.3 dBZ (dash-dot), 20.0 dBZ (dash-dot-dot), and 26.6 dBZ (dot). State outlines are in a dash-dash-dot-dot pattern. Range rings are every 30 km.

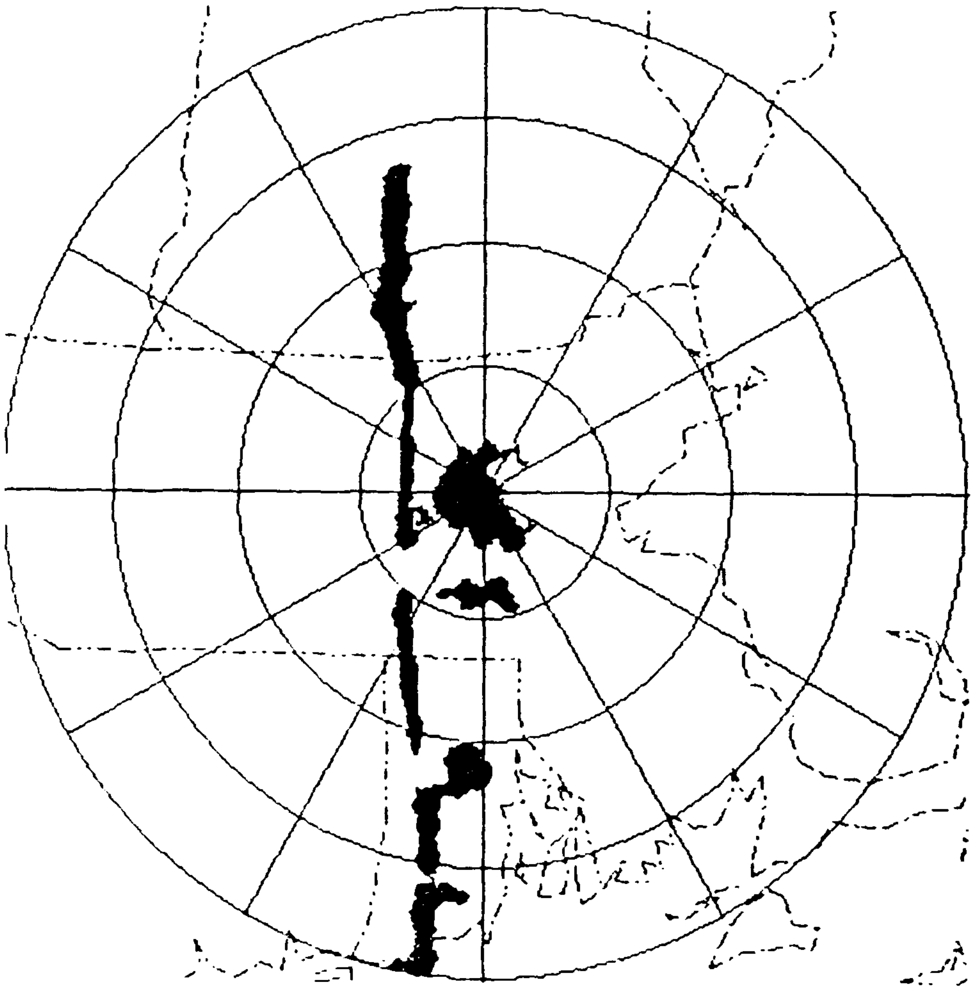


Fig. 8 Area in Fig. 7 where dBZ greater than 20.0 dBZ as depicted by shaded area. Contour used to outline this area was extracted and stored using the Freeman Chain Code approach.

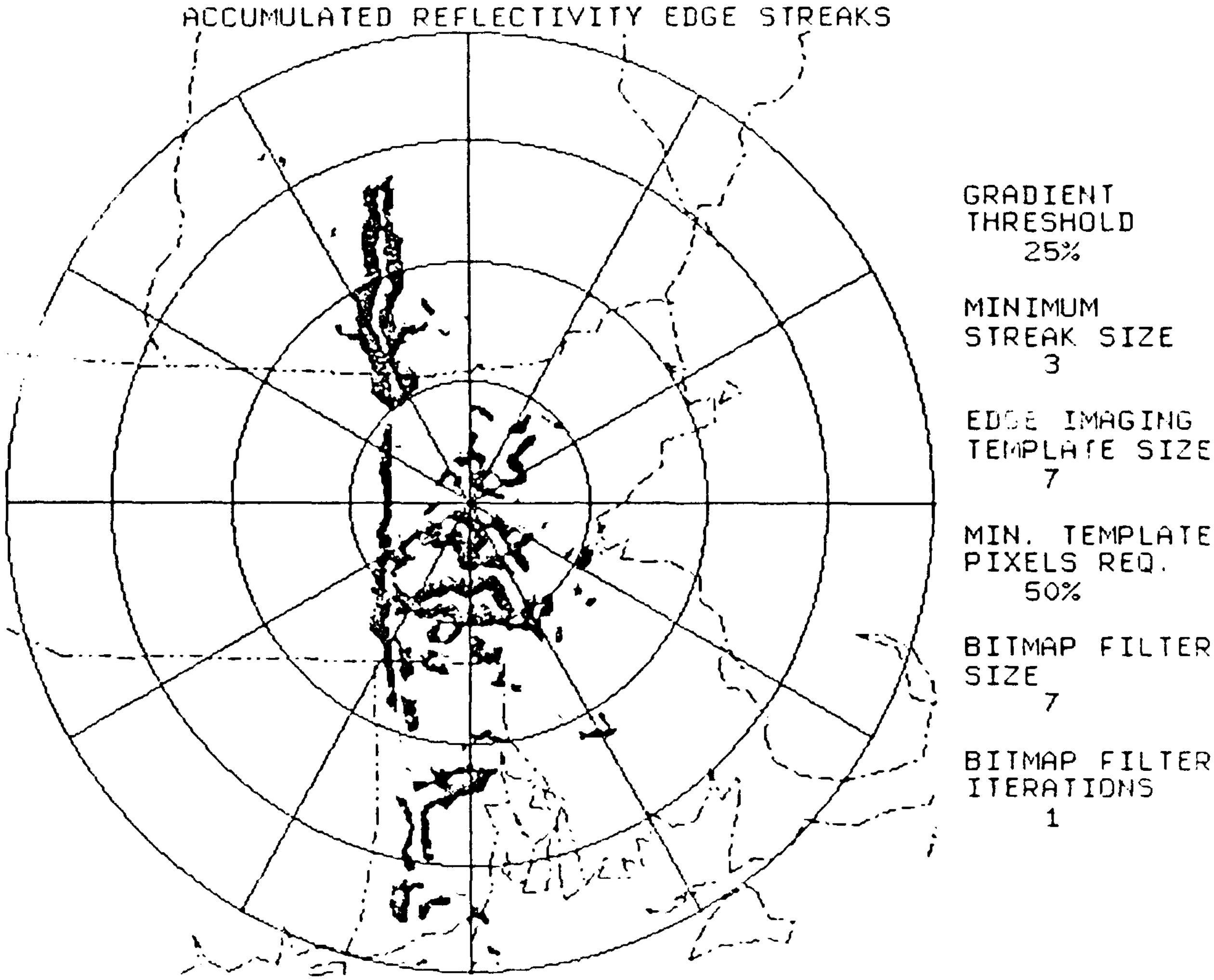


Fig. 9 Edges determined from gradient fields of reflectivity factors displayed in Fig. 7.

using contours lies in the selection of the contour value that will best represent the precipitation area.

Edge detection is also explored as an area representation tool. This technique may not completely delineate a precipitation regime like the contour region but it does accentuate the more significant regions that may need closer attention. Also, a comparison of the contour and edge results can indicate whether the contour is identifying all significant precipitation regions. The contour values might then be raised or lowered as per the edge detection analysis. It should be noted that with further editing of the edges to form contiguous lines (an independent effort) that these lines can also be represented with the Freeman Chain Code and statistics as outlined for the contour can be computed for these edges. In general, any line in two-dimensional space can be represented in Freeman Chain Code, despite origin. This means that data storage and statistical computations can be much more efficient than for standard Cartesian representations.

It appears from this study that the two analysis techniques should be used together to provide a simple but accurate description of precipitation regions. It also appears that representation should be in the Freeman Chain Code format or some reasonable variation of it.

For future work, the following need to be addressed

- Determine applicability in a variety of meteorological situations
- Streamline coordination of two analyses
- Develop forecast techniques for resultant statistics.

These efforts should result in a useful and efficient diagnostic tool for the operational forecaster. In addition, the techniques should have application to other areas in meteorology and elsewhere where the monitoring of image areas is a goal.

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